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Research Paper

The influence of subdivision design and conservation of open space on carbon storage and sequestration

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HIGHLIGHTS

- Used design scenarios to asses impacts on carbon storage and sequestration.
- Old tree stands provided the greatest savings of carbon storage and sequestration.
- Over 91% of existing carbon storage and 82% of sequestration could be maintained.

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ABSTRACT

Cities are increasingly trying to offset carbon dioxide emissions and existing and new residential developments, or urban subdivisions, are a major source of such emissions. Compact or clustered subdivision designs have the potential to improve carbon storage and sequestration through the conservation of open space and the preservation of existing trees found on built lots. However, very few empirical studies assess how different subdivision designs and tree preservation strategies affect the carbon footprint of proposed residential developments. Using a 705 ha pine plantation that has been approved for the development of 1835 residential units near Gainesville, Florida, our objectives were to determine which site designs and tree preservation strategies could maximize carbon sequestration and storage. From 80 stratified random plots, we measured and analyzed tree and plot characteristics according to forest type and tree stand age categories. Tree data collected from these plots were analyzed with the i-Tree ECO model to estimate baseline predevelopment carbon stores and sequestration rates. Using ArcMap, we then assessed the impact, on baseline carbon sequestration and storage capacity, of several different site designs and tree conservation scenarios for the proposed development. Up to 91% of carbon storage and up to 82% of carbon sequestration could be maintained through a cluster urban development design and by preserving older tree stands. Results indicate that a subdivision's carbon footprint can significantly improve when forest types and tree preservation are incorporated into the design of a development.

1. Introduction

As climate change continues to become a serious environmental and societal concern, many urban areas will come under increased pressure to balance continued population growth with greenhouse gas (GHG) reduction. Climate change is a direct result of GHG emissions and a variety of human activities consume fossil fuels and release GHGs into the atmosphere (Malhi, Meir, & Brown, 2002; Soloman et al., 2007). Of these, carbon dioxide (CO_2) is of great concern, making up approximately half of all emissions (Soloman et al., 2007). Since forests store and sequester carbon, conservation and restoration could help offset carbon emissions worldwide (Brown, Swingland, Hanbury-Tenison, Prance, & Myers, 2002). However, globally, forested areas have been in decline for decades and 13 million hectares were lost every year since 2000 (Food & Agriculture Organization of the United Nations, 2010). Causes for deforestation vary based on a region's specific needs

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and can be mostly attributed to land use changes such as agricultural development, urban expansion, and wood extraction (Geist & Lambin, 2002).

New residential subdivisions are usually sited on rural greenfield sites along the edge of existing established urban areas. This peri-urban region typically represents a large source of carbon emissions as forests have been replaced with houses and roads (Zhang et al., 2008). Development typically follows a pattern of clearing a site of all flora, recontouring the site, and then planting trees of similar size and species throughout the entire construction area. When new developments remove existing trees for construction and then plant new trees, carbon stores are released from the destruction of the mature trees and this is followed by a lengthy lag in carbon sequestration as the new trees mature (Escobedo, Varela, Zhao, Wagner, & Zipperer, 2010; Nowak & Crane, 2002). When tree cover is replaced with impervious surfaces or even open park spaces that require mowing, irrigation, and fertilization, areas that were previously carbon sinks can shift to carbon emission sources (Dobbs, Escobedo, & Zipperer, 2011).

When land is subdivided, conserving forests and large individual trees can help minimize a development's carbon footprint by maximizing carbon storage and sequestration (Escobedo et al., 2010; Jo, 2002; Nowak & Crane, 2002). Urban forests can reduce CO_2 emissions through photosynthesis and storage in biomass, and can sequester more carbon than natural forests on a per unit tree basis due to the open forest structure (McPherson, Nowak, & Rowntree, 1994). In addition, trees can shade homes and decrease ambient air temperature through evapotranspiration further limiting CO_2 emissions by reducing energy needs for heating and cooling homes (Jo & McPherson, 2001; Nowak & Crane, 2002). Not only could the overall design of development maximize carbon sequestration and storage, but it could promote a number of other natural resource goals such as conserving wildlife habitat, water quality, and biodiversity (Arendt, 1996; Hostetler, 2012; Milder, 2007).

Conservation developments, areas where homes are clustered together on smaller lots conserving as much greenspace as possible, are alternative subdivision designs that integrate human needs with natural resource conservation (Arendt, 1996; Hostetler & Drake, 2009; Milder, 2007). Conservation developments can reduce the overall carbon footprint of the planned subdivision if the placement of built lots maximizes carbon storage and sequestration for the site. For example, subtropical wetland forests sequester more carbon than upland pine forests (Escobedo et al., 2010), and placing homes in pine forests instead of wetland forests would increase carbon storage and sequestration for developments in subtropical areas. Analyzing the potential impacts of different subdivision designs on carbon sequestration and storage could provide city planners and developers with information on the levels of carbon benefits of one design versus another, which may ultimately improve the overall carbon footprint of a city.

Previous studies of urban tree carbon sequestration and storage have focused on city and land use level estimates in existing urban areas (Escobedo et al., 2010; Jo & McPherson, 2001; Maco & McPherson, 2003; Nowak & Crane, 2002). Little research, however, has explored how different subdivision designs impact carbon sequestration and storage before a development has been constructed. In this study, we selected a forested peri-urban area near Gainesville, Florida that is currently managed for timber. Development approval has been obtained for this site which will eventually contain a mixture of residential and commercial land uses. Our objectives were to (1) determine the influence of different forest types and tree stand ages on carbon storage and sequestration within the site and (2) assess how different subdivision designs impact carbon storage and sequestration. The results of this study will provide some of the information that developers, planners, and designers need to help increase carbon storage and sequestration, and reveal how the structure of managed forests can be used to offset the carbon emissions of households.

Table 1
Seventeen land use land cover (LULC) classifications were grouped into three forest types on the Gainesville 121 site.

Forest type	Land use land cover
Hydric	Bay/Gum/Cypress ecological complex
	Loblolly bay forest
	Swamp forest ecological complex
	Cypress forest compositional group
	Temperate wet prairie
	Forb emergent marsh
	Water lily or floating leaved vegetation
	Saturated-flooded cold-deciduous and mixed evergreen/cold-deciduous shrubland ecological complex
Mesic-Hydric	Mesic–hydric live oak/sabal palm ecological complex
	Mesic–hydric pine forest compositional group
	Broad-leaved evergreen and mixed evergreen/cold-deciduous shrubland compositional group
Xeric–mesic	Xeric–mesic mixed pine/oak forest ecological complex
	Live oak woodland
	Mixed evergreen, cold-deciduous hardwood forest
	Sandhill ecological complex
	Dry prairie (xeric–mesic) ecological complex
	Gallberry/saw palmetto shrubland compositional group

2. Methods

2.1. Study area

The location of this study area is north of Gainesville, Florida on State Route 121 (29° 43′ N, 82° 21′ W). Gainesville is located in North Central Florida, USA and has a population of 125,326 (United States Census Bureau, 2011). Gainesville's climate is humid and subtropical with an average temperature of 12.5 °C in January and 26.2 °C in June. The January mean monthly rainfall is 83.8 mm and in June is 173.0 mm (National Oceanic & Atmospheric Administration, 2011). Over half (56.2%) of soils are a combination of Pomona, Wauchula, and Monteocha loamy sand (Natural Resources Conservation Service, n.d.). This study area, hereafter called the Gainesville 121 site, was chosen because it is in the initial stage of urban development and land owners are interested in determining how carbon storage and sequestration could be improved using different development designs. The development site is currently owned by Plum Creek and is comprised of 705 ha of planted pine, mixed hardwood forest, and wetlands. At the time field work was conducted, the site was approved for 1835 residential units.

2.2. Land cover aggregation

Analysis of land cover raster data generated by the Florida Fish and Wildlife Conservation Commission (Florida Fish & Wildlife Conservation Commission, 2003) using ArcMap software revealed that the study area is comprised of 21 Land Use and Land Cover (LULC) types. Four of these LULC classifications, bare soil/clear-cut, urban residential, agriculture, and pasture/grassland/agriculture, (a total of 18 ha), were excluded because one of the goals of this study was to determine pre-construction tree carbon storage and sequestration in the study area. To better represent the major plant community types in the study area, the remaining seventeen LULC types were aggregated into three forest type classes (hydric, mesic–hydric, and xeric–mesic) based on soil moisture regimes and species composition (Table 1). Forest type classification was determined by comparing metadata descriptions of soil moisture profiles and vegetative species with the LULC classification scheme in Florida Fish and Wildlife's final report (Kawula, 2009) and